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Peer review process

All papers submitted to COBRA were subjected to a peer review refereeing process.

Referees were drawn from an expert panel, representing respected academics from the construction and building research community. The conference organisers wish to extend their appreciation to the following members of the panel for their work, which is invaluable to the success of COBRA.

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APPLICATION OF A BUILDING COST ESTIMATION MODEL TO THE APPRAISAL OF THE CHURCHES DAMAGED BY EARTHQUAKES IN LORCA (SPAIN)

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ABSTRACT

The objective of this paper is the development of a *building cost estimation model* whose purpose is to quickly and precisely evaluate rebuilding costs for historic heritage buildings affected by catastrophic events. Specifically, this study will be applied to the monumental buildings owned by the Catholic Church that were affected by two earthquakes on May 11, 2011 in the town of Lorca. To estimate the initial total replacement cost new, calculation model will be applied which, on the one hand, will use two-dimensional metric exterior parameters and, on the other, three-dimensional interior cubic parameters. Based on the total of the analyzed buildings, and considering damage caused by the seismic event, the final reconstruction cost for the building units ruined by the earthquakes can be estimated. The proposed calculation model can also be applied to other emergency scenarios and situations for the quick estimation of construction costs necessary for rebuilding historic heritage buildings which have been affected by catastrophic events that deteriorate or ruin their structural or constructive configuration.

Keywords: building, earthquake, cost, estimation, model.

1. HISTORY: THE EARTHQUAKES OF MAY 11, 2011

Figure 1- Church of Santiago (Lorca)
Source: Director Plan for the Recovery of the Historic Heritage of Lorca (Murcia)

Located in the southeastern corner of the Iberian Peninsula, the town of Lorca is considered one of the most seismically active areas in Spain, due to its location on the Alhama de Murcia fault, which is considered responsible for the majority of registered seismic phenomena.
On May 11th there were two seismic movements in Lorca and several aftershocks, the first recorded at Mw 4.5 (degree of intensity VI) and the second at Mw 5.1 (degree of intensity VII).
The severe damage to structures substantially affected the housing stock in Lorca, as well as a large number of residential buildings and farming, fishing and commercial installations. The earthquake also caused enormous damage to the city's historic heritage sites.
The restoration of the destroyed heritage sites requires the programming of specific investments, for which it is necessary to quantify the resulting damages economically. This project proposes that valuation of the damages produced by the earthquakes to the Historic Patrimony of the Catholic Church be determined through the practical application of a model for estimating reference costs. To determine its value, the building in question is considered to be composed of the three Vitruvian elements: (1) beauty (an exterior surface parameter), (2) functionality (an interior volumetric parameter) and (3) durability (the building's surface footprint). The cost estimation model proposed here forms part of a larger model, developed in five phases of analysis of increasing complexity and level of precision (figure 2).

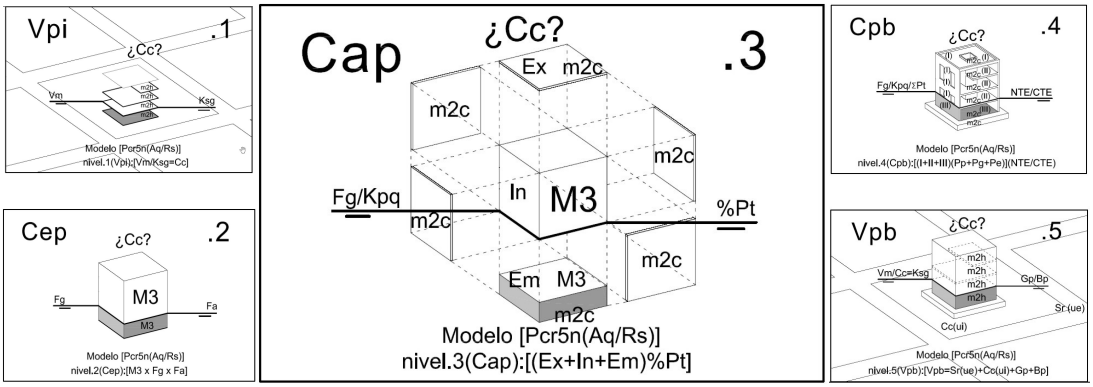

Figure 2 – General cost estimation model.
Source: the authors

2. FORESEEN OBJECTIVES AND HYPOTHESIS FORMULATION

The objective of this study consists of the practical application of a calculation model for the valuation of the reconstruction costs for the historic heritage of the city of Lorca and, more concretely, the churches affected by the aforementioned earthquakes.
The initial valuation of the damages produced to the historic heritage of Lorca by the earthquakes in question, was estimated by the Director Plan for the Recovery of the Cultural Heritage of Lorca (Spanish Ministry of Culture) at 51,287,076.96 € (VVAA, 2011).
The econometric calculation for estimating the costs for replacing the churches with **new construction is carried out using market prices, which are verified against the current database** that is commonly used by the region's real estate sector (Pina, 1989 and 2004).

The calculation process begins by obtaining the replacement construction costs for the churches, and continues, in view of the damage produced by the seismic action to each of the constructive systems, by estimating the reconstruction costs of the structural units that were damaged and/or ruined by the earthquake.
The total initial cost estimation is calculated using two-dimensional exterior metric parameters and three-dimensional interior cubic parameters. Two-dimensional parameters are considered as the surface that wraps around the facade, as well as that which corresponds to the footprint of the building on the plot of land. The three-dimensional parameters are the volumes that correspond to the functional uses of the church's interior spaces.
The estimation of the two-dimensional and three-dimensional synthetic costs is carried out using the traditional analytical method for construction cost estimation, obtained as the sum of the measurements of all the units of work, multiplied by their unitary reconstruction costs. These analytical calculations are then used to obtain the synthetic costs per square meter (envelope) and per cubic meter (interior space).

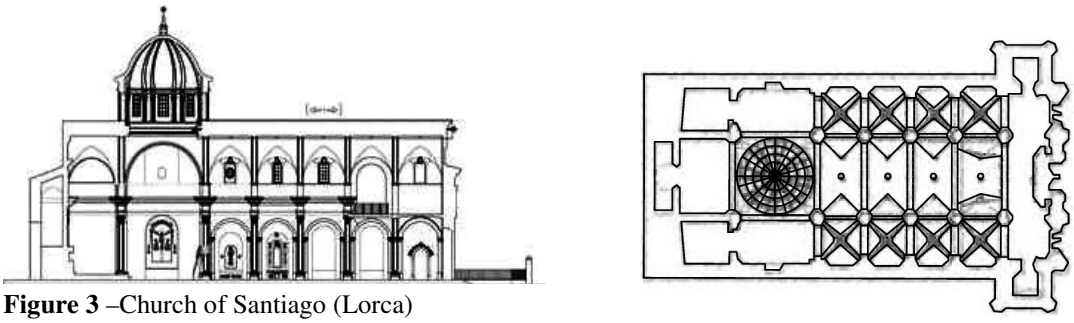

Figure 3 –Church of Santiago (Lorca)
Source: Spanish Cultural Heritage (nº6/2012)

The predimensioning model proponed can also be applied to purposes other than the economic evaluation of the damage caused by an earthquake: for example, calculation of the structural restoration and rehabilitation costs of constructive systems, or the construction of new buildings.
Lastly, the basic aim of the model is to attain deviations between the estimate and final real costs of less than 10%, the maximum permitted by Spanish law (Garcia, 2011).

3. APPLIED METHODOLOGY

The methodology developed for the practical application of the described cost estimation model has been structured in the following way.
First, an analysis was carried out of the scientific publications and technical articles published with regards to the damages caused by the seismic event to Lorca's historic heritage.
The affected churches represent 46% of the total number of existing churches in Lorca's historic district (11 damaged churches out of a total of 24 existing ones).
The next phase consisted of acquiring the technical data on the earthquake and its evaluation, which was done using the aforementioned Director Plan of the Spanish Ministry of Culture (Figure 4). The economic evaluation of the reconstruction of damages to the structures and building systems of the churches caused by the earthquakes was undertaken using data published by the responsible for the corresponding works (De la Hoz, 2012).

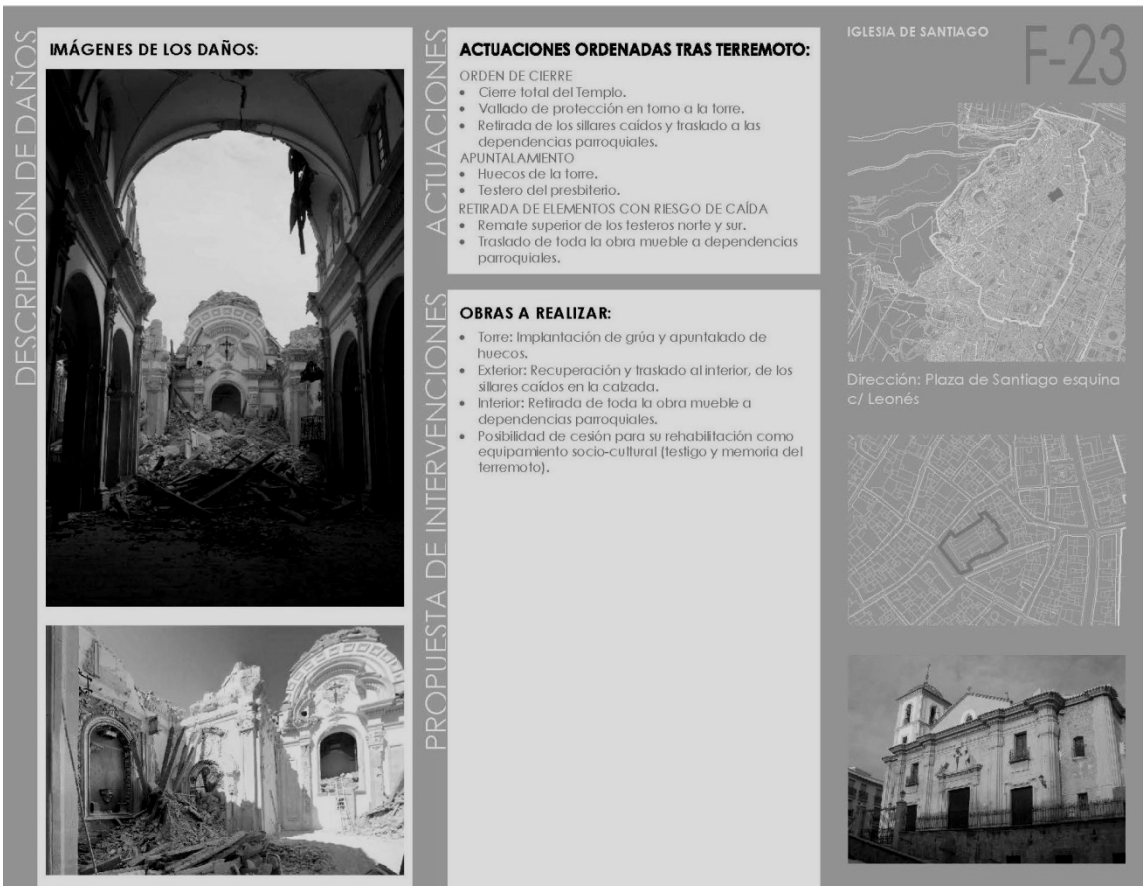

Figure 4 –– Church of Santiago: images of the damage.
Source: Director Plan for the Recovery of the Historic Heritage of Lorca (Murcia)

The replacement and reconstruction costs were obtained on a representative sample of six churches that represent 55% of the total of 11 churches that were affected by the earthquake. These costs were acquired using the product of the measurements of the units of work times the respective unitary prices, taken from the statistical data used by the construction sector in that region (Pina, 1989); the figures were updated in 2012, thereby resulting in values in accordance with real market costs. This procedure makes it possible to obtain the cost of the superficial and volumetric parameters of the work as a whole.

Finally, the described analytical procedure also makes it possible to determine the reconstruction costs, defining the part of the structure affected by the earthquake, and estimating the percentage of its total that this represents. The previously calculated percentage is then applied to the total cost for complete reconstruction of the Church.

4. DATA ANALYSIS, DISCUSSION AND SUMMARY OF RESULTS

The practical application of the cost estimation model used here was carried out on the Church of Santiago, of which 37.42% of the entire building was affected by the earthquakes.

Table 1 reflects the approved investments for the reconstruction works on the churches affected by the earthquakes, indicating that the reconstruction costs for the Church of Santiago reached the amount of 2,144,068 Euros.

CHURCHS	Closing order	Reconstruction costs (€, including VAT)	Reconstruction costs (€ excluding VAT)	Total m^2	Total m^3	Reconstruction costs €/ m^2	Reconstruction costs €/ m^3
1,-Church of Nª Sª del Carmen	Yes	755,000	639,831	1,263	14,585	507	44
2,- Church of San Jose	Partial	810,000	686,441	460	4,140	1,492	166
3,- Church of San Mateo	Yes	915,000	775,424	1,656	21,166	468	37
4,- Church of San Patricio	Yes	2,960,000	2,508,475	2,770	44,320	906	57
5,- Church of Santiago	Yes	2,530,000	**2,144,068**	1,272	15,357	1,686	140
6,- Church of MM Mercedarias	No	1,036,000	877,966	628	7,536	1,398	117
7,- Church of Clarisas	Yes	502,786	426,090	175	1,925	2,435	221
8,- Church of Cristo Rey	Yes	1,207,000	1,022,881	530	5,300	1,930	193
9,- Church of San Cristóbal	Yes	233,000	197,458	1,097	10,970	180	18
10,- Church of San Diego	Yes	735,000	622,881	673	8,076	926	77
11,- Church of Virgen de lasHuertas	Yes	1,375,000	1,165,254	995	11,940	1,171	98

Table 1: Approved budget for reconstructing churches in Lorca (Spain)
Source: de la Hoz, Juan de Dios (2012) and the authors

Table 2 depicts the estimated replacement construction costs for the analyzed churches, with the Church of Santiago represented by a total cost of 6,107,232 €, and by unitary costs of 4,801 €/m2 and 398 €/m3. The table also reflects the reconstruction costs for damages, equivalent to 37.42% of the construction costs for a replacement structure. The estimation error for the Church of Santiago is **6,59%**, with an average deviation of 8.67% from the sample.

	CHURCHS	TOTAL REPLACEMENT COSTS			RECONSTRUCTION COSTS			
		€	€/m2	€/m3	% damages	€ Estimation	Approved investments (Table 1)	% average deviation
1	Church of Nª Sª del Carmen	6,394,569	5,063	438	11.12	711,076	639,831	11.14
2	Church of San Mateo	8,052,456	4,863	380	10.31	830,208	775,424	7.07
3	Church of San Patricio	33,677,660	12,158	760	8.12	2,734,626	2,508,475	9.02
4	**Church of Santiago**	6,107,232	4,801	398	37.42	**2,285,326**	2,144,068	**6.59**
5	Church of Clarisas	563,889	3,222	293	80.45	453,649	426,090	6.47
6	Church of Virgen de las Huertas	3,412,712	3,430	286	38.16	1,302,291	1,165,254	11.76
							average percent deviation in %:	8.67

Table 2 : Replacement construction costs and reconstruction costs (excluding VAT)
Source: the authors

Table 3 displays, in summary, the preliminary calculation of the replacement construction costs for the Church of Santiago and the analytical estimation of the percentage of the structure that had been damaged.

Multiplying all the measurements (x,y,z) of the wok elements by their market prices provides the estimate per chapter and the total costs of new work: 6,107,232 euros.
The percentile calculation of the work to be carried out is made by summing the right hand column corresponding to the percentages representing each of the items with respect to the total work to be carried out. In this case, the sum of the percentages is 37.42%, which, given that the total estimate is 6,107,232 euros represents 2,285,326 euros

Chapter 1		**Structural system (supporting structural work)**		**X**	**Y**	**Z**			**€**	**2,489,221 €**	**49**	11.40
1.1	m2	Foundations and Excavations ship	1	46.00	22.00		1,012.00	1,012.00	290.00 €	293,480 €	**5.8**	0
1.2	m2	Foundations and excavations tower	2	5.60	6.50		72.80	72.80	348.00 €	25,334 €	**0.5**	0
		Cost of hiring per m2 built(1.272 m2c)							**1,272**	**4,801 €**	**m2c**	
		Cost of contract by M3 built(15.357 M3e)							**15,357**	**398 €**	**M3e**	
											%	% Rc
Chapter1		**Structural system (supporting structural work)**								**2,489,221 €**	**49**	**11.40**
		excavation, foundation and structure										
Chapter2		**Surround system (works fine outside)**								**934,589 €**	**18**	**5.75**
		roof and facade										
Chapter3		**COMPARTMENTALISATION SYSTEM (interior)**								**142,283 €**	**3**	**1.62**
		factories and carpentry										
Chapter4		**FINISHING SYSTEMS (interior)**								**1,110,719 €**	**22**	**13.35**
		coatings and paints										
Chapter5		**SYSTEM INSTALLATIONS (conditioning)**								**199,134 €**	**4**	**3.60**
		facilities										
Chapter6		**SAFETY / CONTROL AND WASTE**								**195,038 €**	**4**	**1.50**
		security, control and waste treatment										
		SUM COST PERFORMANCE MATERIAL								**5,089,360 €**	**100**	**37.42**
		more GG + BI										
		Total budget contracted (NO IVA)								**6,107,232 €**	**120**	**2,285,326**

Table 3 : Excel of analytical calculations / Church of Santiago (Lorca)
Source: the authors

Table 4 contains the total replacement cost estimate, calculated from three elements (1) exterior surface envelope, (2) interior constructed volume and (3) footprint area of the building on the plot of land.

(I) CALCULATION A NEW CONSTRUCTION COSTS				
Chapter1	OUTER (outer dimensional metric parameter)	4.135 m2 x	287 €/m2 =	1.186.745 €
Chapter2	INTERIOR (inner dimensional cubic parameter)	15.357 M3 x	295 €/M3 =	4.530.315 €
Chapter3	BUILT (building footprint dimensional parameter)	1.085 m2 x	367 €/m2 =	389.195 €
		COST OF BUILDING FROM NEW=		**6,115,255 €**

(II) CALCULATION RATIO OF CHAPTERS OF WORK **Churches Type 3 - Category average / good -** Intervals predimensioning new costs € / m2c and € / M3e: [4,800 / 5,100 / €/ m2c] and [385/410 / € /M3e] (mean = 12.50 meters Height)		A NEW CONSTRUCTION COSTS		COST OF RECONSTRUCTING DAMAGE	
Description : Church of category 3 average/good built entirely with masonry walls, except the main façade with its stonework frieze, and the coated, partitioned vaulted roof.		% Percentage constructive system	% Percentage chapter	% Percentage construction system	% Percentage chapter
Chapter1	SURFACE WRAP (fine work outside)		19%		**6%**
	cover	3%		**2%**	
	facade	16%		**4%**	
Chapter2	INTERIOR VOLUME (supporting structural work)		74%		**31%**
	Vertical structure	35%		**8%**	
	Horizontal structure	9%		**6%**	
	Facilities	4%		**4%**	
	Partitions	3%		**2%**	
	Coatings	23%		**11%**	
Chapter3	BUILT FOOTPRINT (recessed work area)		7%		**no**
	Foundation	7%		**no**	
	SUM TOTAL PERCENTAGES =	100%	100%	**37%**	**37%**

(III) PREDIMENSIONING COST OF RECONSTRUCTION (Pcr) CHURCH OF SANTIAGO (LORCA)
Pcr =% x damage condition of total new construction = 37/100 x 6,115,255 euros = 2,262,644 €uros
% Deviation percentage "error" = € 2,262,644 / € 2,144,068 (Table 1: excluding VAT) = 1.0553 = 5.53%

Table 4: COST A NEW (level 3 Pcr.5n model). Percentages% new / rebuilt work. Reconstruction cost predimensioning Church of Santiago (Lorca).
Source: the authors

Additionally, the table includes the forecasted percentage of each of the sections under the three aforementioned headings, with the goal of assigning them the percentages of respective damages.
Finally, to fix the cost estimate for the church's reconstruction, it is sufficient to calculate **37%** of the total estimate for replacement construction, which is to say 0.37 x 6,115,255 € = 2,262,644 €, which represents a **5.53%** deviation with respect to the approved investment, which is 2,144,068 € (Table 1).

Discussion of data and results

As a consequence of the development of the cost estimation model applied to the Church of Santiago, we have obtained the following results, in which the deviation percentages are reflected over the real costs specified in the Director Plan:
1/First rough approximation calculation (Table 2) = 2,285,326 € (6.59%)
2/Estimated reconstruction cost calculation (Table 4) = 2,262,644 € (5.53%)
This is verification of the fact that as advancements are made in calculation levels, the accuracy of the estimated value of the approved investment increases.

The precision of the model could be improved by using detailed measurements of the parts that make up the outer envelope of the cover/façade and of the volumes dedicated to different uses inside the building.

The deviations involved in predimensioning the costs could also be reduced by classifying the churches into six types on the basis of the construction quality (Pina, 1991) and historical importance:

Type 1: elementary/simple (mean height, 10 metres)

Type 2: basic/normal (mean height, 11.50 metres)

Type 3: average/ good (mean height, 12.50 metres)

Type 4: very good/superior (mean height, 14.00 metres)

Type 5: singular/excellent (mean height, 16 metres)

Type 6: extraordinary/exceptional (mean height, more than 18 metres)

In this way it would be possible to widen the sample of the churches analysed (55%) to include all eleven (100%) affected by the earthquake, thus improving the precision of the estimated costs

5. CONCLUSION

The validity of the cost estimation model applied to the valuation of the damage produced in Lorca's churches by the earthquakes that occurred on May 11th, 2011 has been proven. The average deviation of the cost approximations is less than the 10% that is commonly accepted by current Spanish legislation. This precision reflects the great interest and potential applications of the model for use as a tool by professionals in the construction industry.

The application of the model is notably agile and fast, without relying on a deep understanding of the properties to be valued. A highly reliable reconstruction cost for the churches is obtained using the measurement of three basic construction concepts combined with a damage estimation percentage, making it possible to determine with an elevated level of precision the investments necessary for restoration of the destroyed historic patrimony.

The characteristics of this model also allow it to be applied to other scenarios and emergency situations, making it ideal for the quick estimation of reconstruction costs for all types of properties affected by the earthquake and other similar catastrophic occurrences.

Other possible applications of the model would include estimating the costs of rehabilitating historical monuments and residential buildings, repairing "sick" constructions, and building new constructions for private and public use.

Lastly, the following lines are proposed for improving the present research:

- Classification of churches into six types based on their construction quality and historical importance.
- Creation of a global data base according to the sample analysed in this work in order to minimize deviations in costs estimates, thus improving the model's precision.
- Developing the research into levels.4 and .5 of the model, detailing the surface measurements (m2) and interior volumes (M3).

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